# STATUS OF MINERAL RESOURCE INFORMATION FOR THE FORT YUMA AND COCOPAH INDIAN RESERVATIONS, ARIZONA AND CALIFORNIA

By

Thomas M. Sweeney                    Robin Bradley
U. S. Bureau of Mines            U. S. Geological Survey

# CONTENTS

# SUMMARY AND CONCLUSIONS

Metallic mineral resource potential for the Fort Yuma Indian Reservation is promising. Lode and placer gold are known to exist at two locations within the reservation, and lode occurrences just outside its boundary offer hope for future discovery of additional placer deposits. Copper occurrences indicated in the Cargo Muchacho Mountains may extend into the reservation.

The potential for a metallic mineral resource within the Cocopah Indian Reservation is unlikely; the only possibility seems to be in bars of the Colorado River where placer gold may exist. No metallic mines or prospects are in this river bottom area and chance of metallic occurrence is extremely low. Some geothermal potential may exist in this area as indicated by a hot water well four miles to the east.

Both reservations have abundant alluvial material which may be used for asphaltic and concrete aggregate and road fill. The Fort Yuma Indian Reservation has abundant gravels derived from nearby mountains. Several deposits have already been worked, and some are still in operation. Because of the mobile nature of uranium and the permeability of local sediments, there is some potential for discovery of uranium deposits. Anomalously high radiation readings in the east and west highland areas indicate possible sources for secondary deposits within the reservation.

Geothermal resources have not been recorded in the reservation; however, known geothermal areas west (Salton Sea), and east (Radium Hot Springs) may indicate some local potential.

Further fieldwork on the Fort Yuma Reservation should include examination and sampling of all nearby lode gold and copper deposits for possible extensions into the reservation. Well, spring, and stream water should be sampled for uranium or other metallic minerals. Then, if warranted, appropriate geophysical studies should be done to trace extensions of mineralized structures into the reservation.

# INTRODUCTION

This report was prepared for the U.S. Bureau of Indian Affairs (BIA) by the U.S. Bureau of Mines (USBM) and the U.S. Geological Survey (USGS). The study was conducted to compile and summarize available information on geology, minerals, energy resources, and the economic development potential of certain Indian lands.

Information is from published and unpublished sources as well as from personal communications. No fieldwork was done.

## Acknowledgments

## Geographic Setting

The Fort Yuma and Cocopah Indian Reservations are located in the southern portion of the Basin and Range physiographic province. This arid region is characterized by isolated mountain ranges rising abruptly from broad desert valleys. The Pilot Knob Mesa, the Cargo Muchacho and Chocolate Mountains are block-faulted ranges, elongated in north or northwest directions. Although elevations in these ranges do not exceed 649 m (2,129 ft-- Stud Mountain), topography of the mountain masses is rugged and steeply sloped. Landforms in the area include dissected old river deposits, piedmont slopes, sand dunes, and river flood plains.

The climatic conditions of this desert region can vary from intense summer heat (118ºF) to severe cold (14ºF) in winter months, with precipitation occurring as localized torrential thunderstorms or as gentle rain. Average annual precipitation is very low: long-term normal rainfall of the Yuma area is 6.4 cm (2.5 in.). Practically all of the rainfall evaporates; sheet flooding and subsurface storage occur only during the wettest periods. The natural vegetation is restricted to the lower Sonoran life zone; sparse creosote bush, cacti, and sage brush cover the higher terrain and non-irrigated lands.

The major drainage and only perennial flowing water in the region is the Colorado River. The Gila River and several ephemeral washes augment the Colorado River with surface water after periodic rain storms. The Colorado River provides water for human needs as well as irrigation water for the agricultural lands on the higher mesas and adjacent to the Colorado and Gila Rivers. Plentiful irrigation water and the long growing season enable several crops to be harvested each year in the Yuma area.

Development of water management programs has been mainly by the U. S. Bureau of Reclamation which authorized the construction of the Yuma Project in 1904, and the Gila Project, reauthorized in 1947. The Yuma project occupies the bottom lands between Yuma and the Mexican border. Since 1941, water has been diverted at the Imperial Canal and carried by the All American Canal across the apex of the Colorado River delta westward to Imperial County, Calif., and southward by canal to the siphon crossing the river to southern Yuma County, Arizona.

## Fort Yuma

The Fort Yuma Indian Reservation includes 41,980 acres in California, T. 15 and 16 S., R. 21, 22, 23, and 24 E. SBBM, and 2,061 acres in Arizona, T. 8 S., R. 22 and 23 W. G & SRBM (Figure 1 and Figure 2). Tribal headquarters are in Yuma, Arizona, directly across the Colorado River from the southern reservation boundary.

Of the 1,752 Quechan Indians enrolled in the tribe, 851 live on the reservation. Average annual income is $5,000/person with a local labor force of 333.

Four commercial businesses, that employ 99 persons, have the potential to contribute $200,000 per year for the tribe. Other than oil and gas, two mineral leases totaling 88 acres have been granted by the tribe (BIA, 1979).

Yuma, Arizona (population 4,115), the largest nearby city, is a center for truck, railroad, and commercial airline travel. Reservation access is generally good with a system of paved streets and highways in the south and east and two secondary roads and jeep trails in the northwest (Figure 2). Several power lines cross the area, and Interstate 80 passes just inside the southern boundary.

## Cocopah

The Cocopah Indian Reservation includes four separate parcels, the east and west reservation parcels and two homestead areas, totaling 2,296 acres in T. 9 and 10 S., R. 24 and 25 W., G & SRBM, near Somerton, Arizona (Figure 3). Tribal headquarters are in the West Cocopah Reservation, 2.5 miles northwest of Somerton.

The tribe has 543 members of whom 465 live on the reservation. The reservation has no mineral industry or leases.(James Crowther, personal commun., 1980).

Somerton, Arizona, is within three miles of all parcels of the reservation; however, Yuma, Arizona, is the largest nearby city and the center for truck, railroad, and commercial airline travel. The reservation is crossed and surrounded by paved and gravel roads.

The climate is similar to that of the Fort Yuma Indian Reservation, 12 miles north. An extensive irrigation network provides ample water to all four parcels.

## History

From the time of its earliest inhabitants, the history of the lower Colorado area has been a remarkable chronicle of man's social and economic development in a challenging environment. Modern culture has evolved from the integration of the heritage from the Indian, Spanish exploration and American westward expansion periods.

The Yuma Indians have occupied the lands near the Colorado River and engaged in agrarian activities since ancient times. The principal crops of corn, squash, beans, and cotton were nurtured by irrigation waters perhaps as early as 500 A.D. This stable economy and sedentary lifestyle stimulated development of social, political, and religious systems and advancement in arts and crafts.

The earliest contact with European civilization occurred in 1540. Hernando de Alarcon was sent as the captain of a Spanish flotilla carrying army supplies to Vasquez de Coronado who was searching for the seven cities of gold. Alarcon discovered the Colorado River and proceeded upstream to just above the junction of the Colorado and Gila Rivers in an unsuccessful attempt to meet with Coronado. Other Spaniards passed through the area but no new knowledge of the region was contributed until the arrival of the evangelizing Father Eusebio Francisco Kino, in 1700. Kino was a Jesuit missionary who crossed the lower Colorado to determine that Baja California was not an island, as was believed in the Spanish settlements of Mexico. In 1701, Father Kino summarized his geographic studies by drawing the first fairly accurate map of the mainland and the Baja peninsula.

When Lieutenant-Colonel Juan Bautista de Anza passed through Yuma in 1774 during his first expedition to Monterey and San Francisco, he left two missionaries to convert the friendly Yuma Indians. Fray Francisco Graces and Padre Tomas Eixarch stayed until de Anza's return two years later. In 1780, the two fathers, accompanied by a small army of Spanish soldiers and their families returned to establish the Mission de la Purisima Conception near the present site of Winterhaven. The Yuma uprising of 1781 wiped out the establishment and closed de Anza's land route to San Francisco. It was during the brief tenure of the Spanish at Winterhaven that placer gold was first mined near the Potholes, 16 km (10 mi) northeast of the mission.

Although American trappers and traders frequented the area in the early 1800's, the regional geography was not known to Americans until the U.S. Army started to explore the western boundaries of the republic. In 1846, Lieutenant W. H. Emory made a geographic record as he accompanied General S. W. Kearney and Kit Carson on a reconnaissance survey from the Rio Grande to San Diego. The first practical wagon route was established in the next year when Captain Phillip St. George Cooke led the Mormon Batallion along the old Spanish trail. With the construction of Fort Yuma guaranteeing safe passage to California, the Yuma area became the nerve center of the region and a main stop on the southern transcontinental mail routes.

Mining activity blossomed under the protective arm of the U.S. Army and the arrival of steamboat traffic on the Colorado in 1852. The discovery of gold placers on the Gila River caused a brief

bonanza in the region, but declined abruptly due to inadequate technology and insufficient water for placer mining. However, the advent of a coast-to-coast railroad within hauling distance of the Laguna, Picacho and Cargo Muchacho mining districts revived mineral exploration and prospecting. Renewed activity included old workings in the Cargo Muchacho Mountains and Potholes vicinity. Peak production years were 1890-1910 and 1937-1942. It is estimated that over $2 million was taken out.

The construction of the irrigation canals and dams on the Colorado River has provided water for further development of the mining industries. The expansion of the water control system and building in the Yuma area has depended on the mining industries to provide construction materials of brick and sand and gravel, thus supporting a steady growth and continued development of natural resources.

## Map Coverage

The topography of the Fort Yuma and Cocopah Reservations is shown on Figure 4. Topographic maps of the reservations may be ordered from the U.S. Geological Survey, Denver Federal Center, Denver, Colorado 80225 (Figure 5).

Small scale geologic map coverage is available on a 1:500,000 map of the geology of Arizona (Wilson, 1969); a 1:375,000 geologic map of Yuma County, Arizona (Wilson, 1960); a 1:250,000 geologic map of California, San Diego-El Centro sheet distributed by California Division of Mines; and, a 1:125,000 geologic map of Imperial County, California (Morton, 1966).

Reservation boundary maps are available from the U.S. Department of Interior, Bureau of Indian Affairs (BIA), Phoenix Area Office, Phoenix, Arizona.

## GEOLOGY

## Previous Investigations

This report summarizes the available published and unpublished information concerning the geology, development, and production of mineral resources on the reservations. Past geologic mapping has been mainly speculative, consisting of reconnaissance studies, either as part of groundwater assessment or in conjunction with California and Arizona state mapping programs. A few university theses have further described the vicinity of the reservations, but the geologic history of the lower Colorado River area has remained largely unknown.

The most comprehensive geologic studies are those published after 1970 and include: Olmsted and others (1973) who described the geohydrology of the Yuma area; a generalized geologic map and description of the geology and mineral resources of Imperial County, Calif., prepared for the California Division of Mines and Geology by Morton (1977); the geology of the basement rocks as described by Haxel and Dillon (1973) and Haxel, (1974, 1977). Structural relationships and tectonic activity along the San Andreas fault system in southeastern California have been discussed by Crowell (1973, 1975), Haxel and Dillon (1973), and Crowe (1973, 1978). Other reports concerning the geology and

mineral resources of the reservations lands are listed in the bibliography.

## Introduction to Rock Units

Rock units exposed on the Yuma and Cocopah Indian Reservations vary in composition from hard crystalline rocks in the mountains to extensive unconsolidated alluvium covering the plains. The rocks range in age from Precambrian (greater than 1.2 b.y. (billion years) old) to Holocene (less than a few thousand years old). The precious-metal deposits are found in crystalline rocks of pre-Tertiary age especially along fault and schistose planes in gneiss and metaconglomerate. The gneiss seems to be the more favorable host as indicated by the greater number of deposits it holds. The source of the mineralization is not certain, but seems to be related to the emplacement of granitic rocks in the Mesozoic(?) period. Placer deposits are mostly contained in Quaternary stream gravels, while the only known occurrence of copper in the area is confined to metavolcanics. A generalized geologic map (Figure 6 and Figure 6a) shows the different rock units described in this report. Stratigraphic relationships are depicted in Figure 7.

## Pre-Phanerozoic Metamorphic Rocks

The rocks of known and probable pre-Phanerozoic age consist of predominantly mafic, ultramafic meta-igneous rocks, metasedimentary laminated gneiss and schist intruded by granitic gneisses. Several lode gold deposits occur in these rocks. These rocks crop out at Pilot Knob, the Picacho and Cargo Muchacho Mountains. They have a

typically gray mottled color when viewed from a distance. Topographic expression is characterized by moderately steep rugged terrain.

The pre-Phanerozoic rocks are the oldest exposed material in the area and are confined to the upper plate of the Chocolate Mountain thrust. They have been affected by at least one episode of amphibolite-facies metamorphism; overprints from numerous metamorphic events obscure most of the original structures and textures. Although older metamorphic features are preserved in a few exposures, the foliation and lineation imposed by the last metamorphic event is of regional extent and parallels the Chocolate Mountain thrust which lies to the northeast in the Chocolate Mountains.

## Tumco Formation

The Tumco Formation crops out in the Cargo Muchacho Mountains and Picacho area and is composed of two lithologies: quartzofeldspathic laminated gneiss of arkosic composition and hornblende schist. Light-gray, medium-grained laminated gneiss comprises approximately 95 percent of the Tumco Formation. Thin intervals of quartzite, marble, amphibolite, and amphibolite dikes occur in minor amounts. The compositional laminations and bands are suggestive of sedimentary or volcanic origin. Supporting evidence for a sedimentary origin is provided by fist-sized ovoid bodies of calc-silicate minerals in the northern Cargo Muchacho Mountains which are interpreted as relict concretions. Amphibolites of meta-sedimentary or volcanic origin occur as thin beds with banding and gradational contacts parallel to the laminations in the surrounding quartzo-

feldspathic gneiss. Amphibolite also occur as sharply bounded, locally discordant layers interpreted as metamorphic dikes and sills. The amphibolite dikes and sills cutting laminated gneiss in the southeastern Cargo Muchacho Mountains and at Pilot Knob are composed almost entirely of hornblende and plagioclase. The dikes may have originated from the mafic complex, as they are in close proximity to more extensive outcrops of amphibolite in the mafic complex.

## Vitrifax Formation

The Vitrifax Formation is an unusual sheetlike body of kyanitequartz rock found near the west end of the American Girl canyon in the Cargo Muchacho Mountains. Some of the richest gold deposits of the area are located in or near the Vitrifax Formation. These rocks may have been produced by leaching of the Tumco Formation by supracrustal fluids originating from the later Mesozoic biotite granite intrusion. To the west and northwest, the Vitrifax Formation grades into laminated gneiss of the Tumco Formation; to the south it is partly bounded by the mafic complex. The Cenozoic American Girl and Padre-Madre-Araz faults offset the cyanite-quartz rocks. The American Girl fault may be a slightly offset contact between the biotite granite and the Vitrifax Formation, thus explaining the apparent localization of ore deposits along the fault. Alternatively, the mineralization resulting from the Mesozoic intrusion may have been redistributed along the fault zone during Tertiary activity.

and uranium are genetically related to the emplacement of the Mesozoic intrusive rocks.

## Granitic and Related Rocks

Hornblende-biotite quartz monzonite occurs in the southern Cargo Muchacho Mountains and consists of three facies. The most common is a slightly blastoporphyritic facies which is found in a complex contact zone with the Tumco Formation. It is in turn intruded by coarsely blastoporphyritic facies. Migmatites along the contact zone with the pre-Phanerozoic mafic complex, are the third facies. The quartz monzonites are polymetamorphic, with relict igneous and mylonitic textures.

Remobilization and recrystallization make many contacts difficult to interpret. Foliations in the quartz monzonite are intruded by biotite granite. Aplite and pegmatite rocks cut foliations in all the older rocks except for the biotite granite. Although some of the dike material may originate from the biotite granite, field relations indicate that several ages of intrusions are probably represented and much of the aplite and pegmatite is younger than the granite. The dike rocks are also orthogneisses but do not have apparent polymetamorphic textures since they lack minerals which show characteristic metamorphic textures. Chloritized dikes which intrude the granitic dikes have locally disseminated iron sulfides ore.

## Metavolcanic and Metasedimentary Rocks of the McCoy Mountains Formation(?)

Metavolcanic and metasedimentary rocks tentatively correlated with the McCoy Mountain Formation crop out in a small area west of Imperial Dam. The pyrite-bearing rocks of this unit are composed of metasandstone, metaconglomerate, metavolcanics, mainly meta-andesite, and minor limestone. The rocks are characteristically dark gray or gray green and tend to have subdued topography. The unit is probably late Paleozoic or Triassic age. The Trio and Senator gold mines are located in these rocks, although the genesis of these deposits does not seem to be related to the occurrence of the formation.

## Tertiary Nonmarine Sediments

A great variety and thickness of Tertiary nonmarine sediments, pyroclastic and volcanic rocks are exposed in the Yuma area; these rocks represent accumulation since Miocene time in a broad basin that generally corresponds to the present configuration of the area. The volcanic rocks may be of economic significance as host rocks for manganese deposits and source of volcanic rock products.

## Breccia, Conglomerate, and Redbeds

Breccia, conglomerates, and redbeds unconformably overlie gneissic rocks in the southern Picacho area. The sequence of sedimentary and associated volcanic rocks appear to have been deposited prior to the time when the Colorado River entered the Yuma area. The nonmarine sediments are strongly to weakly indurated clastic rocks and range from fine-grained mudstone and shale to megabreccia and boulder conglomerate of

fanglomeratic and lacustrine origin. The conglomerate sequence lies unconformably upon the crystalline rocks and the metavolcanic and metasedimentary McCoy Mountain Formation and underlies the older andesite volcanic sequence.

The basal part is composed of arkose, conglomerate, mudstone, fine-grained tuffaceous beds and bentonitic ash which are a distinctive red color. In the Picacho area, a breccia-conglomerate sequence is the dominant rock type. It is composed of heterogeneous material, and typically includes angular to subangular fragments of all sizes as much as many feet in diameter, composed of fine-grained varicolored metasedimentary and metavolcanic rocks. The matrix is an earthy greenish-gray color and consists of clayey sand and silt. The sequence appears to have formed as mudflows, talus, and colluvium as well as fanglomerates. Bedding is obscure and truncated by poorly exposed faults which make thickness difficult to estimate. Maximum exposed thickness probably exceeds 152.4 m (5,000 ft). Both the redbeds and the breccia conglomerate have been moderately deformed; bedding generally dips 30 to 60 degrees in west to southwesterly direction. The conglomerate rocks are probably pre-Miocene in age and may be partially contemporaneous with the Kinter Formation mapped by Olmsted in the nearby Laguna Mountains. Unnamed coarse breccia and conglomerate of probable Tertiary age also occur in the east-central Cargo Muchacho Mountains.

## Extrusive Rocks

Intermittent volcanism occurred concurrently with deposition of nonmarine sediments during the Tertiary. A thick section of the volcanic rocks crops out in the Picacho area and includes several compositional types: (1) Older andesite, (2) pyroclastic rocks of silicic to intermediate composition, and (3) basaltic andesite or basalt. K-Ar dates of the volcanic sequence range from 24.7± m.y. to 26.3± 1 m.y., late Oligocene to early Miocene age. This relatively small spread of the apparent ages suggests the volcanic rocks were extruded within a short period of time.

## Older Andesite

The oldest volcanic rocks are andesitic flows, pumiceous tuff, shallow intrusive bodies, agglomerate, flow breccia, and a basal breccia conglomerate (previously described). The flows lack pronounced primary structures such as flow banding; they are cut by closely spaced irregular fractures. Coloring ranges from dull gray to dull red. The flows are predominantly very fine grained and partly glassy; small phenocrysts of plagioclase, pyroxene, or hornblende are present in small quantities. The tuff is colored light gray, and contains small amounts of biotite, hornblende, and pyroxene. Inclusions of fine-grained andesitic and glass fragments are scattered throughout the tuff. The total thickness of these older rocks probably does not exceed 305 m (1,000 ft). They are exposed in the western part of the Picacho area. An apparent relationship exists between the volcanic rocks and occurrence of manganese in surrounding areas; the general distribution of manganese deposits coincides with that of the volcanic rocks

## Pyroclastic Rocks of Acidic to Intermediate Composition

Light-colored, friable, pumiceous ash-fall tuff and red densely welded ash-flow tuff (ignimbrite) overlie the older volcanic rocks, in some places unconformably. The tuffs, both welded and unwelded, contain mostly glass shards with occasional small pieces of fine-grained to glassy volcanic fragments. Several beds of water-lain tuff and tuff breccia are also present. The pyroclastic sequence attains a thickness of about 457 m (1,500 ft), although displacement along poorly exposed faults renders estimates of unit thickness difficult. Although the rocks have no present economic value, the possibility exists that these rocks may provide a source for construction materials.

## Basaltic Andesite and Basalt

Resistant dark basaltic andesite and basalt form prominent ridges and have a maximum exposed thickness of approximately 305 m (1,000 ft). The intermediate to mafic flows overlie breccia conglomerate with angular discordance, and also rests unconformably over older volcanic rocks. In some places they are overlain by silicic to intermediate tuffs. These rocks are also truncated by poorly exposed faults. The basalt rock is composed of several distinct flows, colored medium gray to darkish brown gray, except for weathered surfaces which are coated with dark brown desert varnish. The flows are more or less vesicular, and some are brecciated, probably from flowage after the lava had begun to solidify.

## Silicic to Intermediate Intrusive Rocks

Dacite or latite porphyry plugs and rhyodacitic dikes intrude granitic and metamorphic rocks in widely scattered occurrences. The intrusive rocks are overlain by late Tertiary nonmarine sediments. The mid-Tertiary intrusive rocks are probably comagmatic with extrusive volcanic rocks since both the intrusive and extrusive phases share distributional, chronological, chemical, and petrologic similarities. The intrusive rocks are often a patchy red color and are relatively resistant to erosion. The dikes are generally small but abundant especially along arcuate faults in the Laguna Mountains. Some ore deposits of copper, lead-silver, silver manganese, and uranium are localized along dikes and faults in the surrounding areas.

## Conglomerate of the Kinter Formation

These rocks consist of predominantly coarse grained nonmarine sedimentary rocks and minor intercalated beds of tuff and ash. The unit is exposed in the Laguna Mountains to the southeast of the Laguna Dam. The Kinter Formation underlies the fine-grained deposits of the Bouse Formation. The age of the Kinter Formation is well established as Miocene on the basis of radiometric dating and stratigraphic evidence. The Kinter Formation is divided into two unnamed members: the lower is composed of coarse unsorted breccia and tongues of brown and gray arkosic sandstone and gray to pink tuffaceous mudstone; and the upper is composed of yellowish-gray fanglomerate and soft arkosic sandstone and mudstone.

The underlying volcanic rocks and the Kinter Formation have generally been deformed by normal faulting and tilting or folding with bedding dips of less than 35º.

## Conglomerate of Bear Canyon

Middle to upper Miocene fanglomerate of Bear Canyon consists of moderately indurated inter-bedded sandstone, heterolithic conglomerate, and breccia. The unit has been folded and upended locally, but in most places it is tilted between 5º and 20º. It is exposed in the western Picacho area in a few outcrops in the Cargo Muchacho Mountains. The fanglomerate unconformably overlies mid-Tertiary volcanic rocks and older basement rocks and is locally unconformably overlain by the Bouse Formation. The Bear Canyon fanglomerate may be laterally equivalent to older marine sedimentary rocks that occur in the subsurface south of the Cargo Muchacho Mountains.

## Tertiary Marine Sedimentary Rocks

Marine sedimentary rocks have been penetrated by several oil test wells and water-test wells in the Yuma area. These mostly fine-grained rocks represent marine and possibly brackish-water environments and are limited to the subsurface. The marine deposits are divided into two units which are separated by an angular unconformity: (1) a more indurated older sequence, and (2) a younger, generally finer grained sequence assigned to the Bouse Formation by Olmsted (1973). A dip log from an oil-test well shows the older marine rocks to be conformable over underlying non-

marine deposits. The older marine sedimentary rocks are more deformed than the Bouse Formation sequence, although both units are broadly warped and faulted.

## Older Marine Sedimentary Rocks

These rocks consist of indurated light-gray fine-grained sandstone with approximately sub-equal amounts of interbedded medium- to dark-gray siltstone and claystone. Beds of ash or tuff are also reported to be within the older marine sequence. Maximum thickness of these rocks may exceed 1,000 ft. Fossil assemblages include foraminifers and mollusks indicative of a marine environment. The fossils are not age diagnostic, but the stratigraphic position of these beds suggests that they interfinger with nonmarine deposits of the Kinter Formation of Miocene age.

## Bouse Formation

The younger sequence of marine sedimentary rocks in the Yuma area is assigned to the Bouse Formation by Olmsted (1973) on the basis of similar lithology and stratigraphic position and an identical foraminiferal fauna. These marine deposits consist of silt and clay with minor very fine to fine sand, hard calcareous sandstone or sandy limestone, tuff, and possible conglomerate of local derivation. The clay and silt are pale greenish gray to bluish gray, some strata are pink and brown. The sand is well sorted and a light gray color. The basal calcareous sandstone or sandy limestone is very pale gray to grayish yellow with locally abundant marine fauna including corals and mollusks.

Several species of foraminifera and organic remains, both plant and animal, are numerous in some zones. These flora and fauna are said to be representative of brackish to marine environment but are not diagnostic as to age.

Only a few cuttings of a probable tuff bed about 2.7 m (9 ft) thick were recovered during drilling; this unit overlies the limestone/sandstone. A conglomerate and arkosic sandstone composed of granite and metamorphic clasts containing a 0.9 m (3 ft) bed of claystone and a 1.8 m (6 ft) stratum of sandy limestone, underlies part of the upper clay, silt, and fine-sand beds. The conglomerate and sandstone beds may represent beach gravels or offshore bars.

The Bouse Formation is wedge shaped and attains a maximum thickness of 289 m (950 ft). These younger marine sediments are limited to the subsurface in the Yuma area but are most likely more extensive than the older marine sequence. They appear to be less deformed than the older marine and nonmarine deposits, and were probably deposited after the mountain masses took their present configuration, but before they assumed their present altitude.

Little additional evidence for the age of the Bouse Formation is available in the Yuma area. A lower limit of Miocene is well established since the Bouse overlies the Kinter Formation with some local angular discordance. Metzger (1968) has concluded that the Bouse Formation in the Parker-Blythe-Cebola area, to the north, belongs within the Pliocene; and, as in the Parker-Blythe-Cebola area, no Colorado River alluvium occurs below or within the younger marine sediments, so the Bouse

Formation antedates the entrance of the Colorado River into the Yuma area.

## Transition Zone

A transition zone of intertonguing marine and nonmarine strata tops the Bouse Formation and represents alternating marine and subareal deposition. This interval is of Pliocene age and reaches a thickness of several hundred feet in the southwestern Yuma area. The top of the transition zone is defined by the uppermost bed of fossiliferous gray clay or silt, the base by the lowest most alluvial bed of sand or gravel.

## Tertiary and Quaternary Older Alluvium

The older alluvium consists of a great range of material varying from clay to cobble-boulder gravel, and originates from local streams as well as the old Colorado and Gila Rivers. Dissected stream terrace and piedmont deposits cover areas near the mountain masses. These subareal sedimentary rocks represent several cycles of alluvial filling separated by degradation related to fluctuations in sea level. Different alluvial fill cycles of the older alluvium are commonly defined by unconformities and are the most widely exposed deposits in the Yuma area. Changes in sea level were associated with glacial and interglacial stages as well as regional and local warping of land surfaces. Unit thicknesses range from 0 up to a maximum of 762 m (2,500 ft) in the southwest. This great thickness of sediments indicates subsidence during deposition since the alluvium was deposited on the surface that is now several hundred meters below

sea level. The age of the older alluvium ranges from Pliocene to late Pleistocene and is linked to the establishment of the Colorado River and later Gila River as through flowing streams. McKee (1967) has determined that the Grand Canyon was cut to nearly its present depth by mid-Pleistocene, which implies canyon-cutting and sediment transport by the Colorado River must have started well before the Pleistocene. The older alluvium stratigraphically separates the transition zone-Bouse Formation from the younger alluvium (most recent sedimentary cycle).

## Conglomerate of Chocolate Mountains

The conglomerate of the Chocolate Mountains unconformably overlies the late Miocene fanglomerate of Bear Canyon. The conglomerate is probably middle to late Pliocene age and is nearly continuous with the Bouse Formation. The conglomerate is the lowermost section of the older alluvial cover, and is overlain by loosely consolidated deposits of late Pliocene to early Pleistocene alluvium.

The conglomerate of the Chocolate Mountains occurs as a deeply dissected alluvial apron and contains clasts of local origin. The deposits range from conglomerate to sandstone, siltstone, and breccia; they are slightly to moderately consolidated. The conglomeratic beds have been tilted, faulted, and eroded prior to deposition of overlying alluvium.

## Deposits of Local Origin

The deposits of local origin were probably deposited as alluvial fans. These poorly sorted thick masses of debris form low hills and dissected highlands along the margins of the area. They are typically poorly bedded with scour and fill structures. Individual strata are poorly defined and lenticular. The deposits consist of angular to subangular gravel in a silty or clayey sand matrix. Composition of the gravel reflects local rock types.

## Stream-Terrace and Piedmont Deposits

The stream-terrace and piedmont deposits consist of ill-sorted gravel with much sand, silt, and clay. They often overlie older fill in the older alluvium from which they are difficult to distinguish. The piedmont deposits were formed by cycles of sheetfloods and shifting ephemeral streams; the stream terraces accumulated at different levels along the larger washes. Most exposures of both types of deposits are covered with a mosaic of stones termed "desert pavement." The stones are often coated with "desert varnish" which consists of oxides of manganese and iron.

## Deposits of the Old Colorado and Gila Rivers

By far the most abundant alluvial fill comes from the ancestral Colorado and Gila Rivers. These deposits differ significantly from deposits of local origin. Sediments are better sorted, more rounded, and less heterogeneous on a local scale. These deposits are horizontally continuous beds which can be traced for several miles.

The greatest bulk of the old river deposits consists of sand, which is frequently crossbedded. The sands are mostly feldspathic but contain an

amphibole-augite-garnet heavy-metal assemblage. Gravel is the next most abundant material and is also frequently crossbedded. Cementation, generally by calcium carbonate, is characteristic of the old river gravels.

Clay and silt strata are locally conspicuous but minor constituents compared to the sand and gravel of the older river deposits. Abundant fossil twigs, roots, and root fillings in the clay and silt layers suggest a slack-water depositional environment, perhaps on broad flood plains. Some of the clay and silt layers can be traced for several miles.

## Quaternary Younger Alluvium

The younger alluvium represents sediments from the most recent major cycle of deposition. The deposits are divided by agents of deposition into three categories: (1) deposits of the Colorado and Gila Rivers, (2) wash and sheet wash deposits, and (3) windblown sand. These recent sedimentary units underlie the present river flood plains and the washes. The soils of the younger alluvium generally lack mature profile development. They reflect the dominant process of aggradation during the last several thousand years, although some local degradation has occurred in the recent past.

## Younger Deposits of the Colorado and Gila Rivers

The younger river deposits are mainly composed of sand and silt which have been laid down on the pebbly sand and silt of present flood plains. They are abundant in places. One extensive bed of silt and clay has probably resulted from repeated overbank flow during flooding. The younger river

deposits are similar to the older deposits except they are generally less cemented. A basal gravel unit identified by Metzger and others (1973) in the Parker-Blythe-Cebola area has been dated as less than 10,000 years. This unit does not occur as a pervasive subunit in the Yuma area, although it may be present in the western part of the area. The gravel was probably the first clastic material to be dumped by the Colorado River as sea level rose after the retreat of the Wisconsin glacial stage.

## Wash and Sheetwash Deposits

Deposits of sand and gravel with lenticular beds of silt occur in washes and channels. These deposits are generally thin and cut into older alluvium and prealluvial rocks. The sheetwash deposits resemble alluvial fans but generally blanket older rocks in broad, poorly defined sheets rather than thick wedges like true alluvial fans.

## Windblown Sand

The windblown deposits are composed of well-sorted, fine to medium sand, probably derived from old lacustrine or marine beaches. The sand grains are subrounded to rounded and composed of quartz with minor feldspar, rock fragments, and heavy minerals. Many of the grains are frosted. The sand deposits are extensive and form large sinuous and arcuate dunes as well as thin sheets of windblown material. One small area of low dunes and sand sheets lies 5 to 6.5 km (3 to 4 mi) north of Yuma and is adjacent to a Colorado River meander channel which was cut off in historic times.

## STRUCTURE

The major structural features in the area can be divided by the time of their development. Epochs of deformation are limited to: 1) pre-Tertiary crystalline rocks; 2) uplift of mountains and basins to approximately their present outline by Tertiary time; 3) subsidence of the Salton Trough during Cenozoic time; 4) warping and tectonic activity along the San Andreas and related fault systems continuous throughout Tertiary and Quaternary time.

Old fault and joint systems cut the pre-Tertiary crystalline rocks; many of the faults are mineralized and filled with dikes and quartz veins. The last major deformation to affect only the crystalline rocks was the Laramide orogeny, which extended from late Cretaceous into early Tertiary time. Igneous activity, extensive folding, reverse and normal faulting occurred during this mountain-building event. Precambrian gneissic rocks were thrust over Mesozoic-age schists to the north of the area by the Chocolate Mountain thrust (outside the area shown on Figure 6); associated metamorphic foliation and lineation were developed during the emplacement of the upper plate of the thrust sheet.

The present configuration of the mountain ranges in the Yuma area may be partially related to block faulting and domal uplift that originated during the Laramide orogeny; however, most of the outlines of the ranges resulted from Tertiary Basin-and-Range faulting. The present mountain fronts are mostly erosional, with the frontal faults buried by alluvium in the basins between the mountain masses.

The southern part of the Salton Trough has been filled with a thick sedimentary wedge. The nonmarine and volcanic rocks of Tertiary age unconformably overlie the crystalline rocks, and are in turn separated by an angular discordance from the overlying marine Bouse Formation, transition zone, older and younger alluvium. The Bouse Formation and younger sedimentary rocks are substantially less deformed than the nonmarine and volcanic rocks which have been considerably affected by broad folding and warping. Nonetheless, most of the late Tertiary and Quaternary have undergone some local faulting and broad warping and tilting, probably related to subsidence in the Salton Trough.

The northwest-trending branches of the San Andreas fault system extend from the Salton Trough southeastward to Mexico. Displacements along the system have been right lateral and may have amounted to as much as 160 miles since early Miocene in southern California. Unaffected alluvium and windblown sand conceal traces of the fault system, but geophysical data suggest the system continues across the Yuma area. The last significant movement along one of the major traces, the Algodones fault, occurred before latest Pleistocene and is concealed beneath unaffected alluvial deposits in the Yuma Mesa and Yuma Valley (Figure 6).

## ECONOMIC GEOLOGY

### Fort Yuma

Local mineral production has been from lode and placer gold, copper, and sand and gravel

deposits. Geologic conditions favorable for these minerals occur throughout the reservation area and indicate some potential for future discovery of presently unknown deposits.

Lode gold deposits just outside the northeast corner of the reservation are associated with quartz veins in porphyroblastic metagranites. Free gold occurs in quartz breccia with secondary galena and wolframite; the associated country rocks are schists and metaconglomerates. Structures generally trend northwest, but some strike northeast. Brecciation appears to have been caused by renewed movement along a fault after mineralization occurred.

Coarse placer gold, indicating a local source, is found near the Colorado River and on older stream terraces. Dry placer mining occurred on what is now reservation land as early as 1780.

A mineral deposit in the northwest corner of the reservation yielded gold and copper from quartz veins which trend N. 80ºE. The veins are composed of small lenticular bodies of quartz in monzonite country rock. These bodies are reportedly only a few feet wide and a few tens of feet long.

Sand and gravel occurs throughout the reservation, and many deposits have been developed (Figure 2). This Holocene river alluvium is valuable as aggregate in building and as road fill. The two sources of this material are the Colorado River and the local mountains.

Uranium, though not previously indicated in this area, could occur at depth in the coarse sediments. The nearby granitic mountains may be a good source, and organic material within the alluvial deposits could have concentrated the uranium.

## Cocopah

The reservation is entirely covered by Quaternary alluvium and no mines or prospects have been located. This land appears to be barren of economic minerals.

## MINERAL RESOURCES

## Metallic Mineral Resources

### Fort Yuma

Several metallic mineral resources occur on or near the reservation. Most of them are in the northeast and northwest corners of the reservation on the edges of the Chocolate and Cargo Muchacho Mountains, respectively. The rest of the reservation is covered by a thick layer of alluvium that conceals the basement rocks.

### Cargo Muchacho District

This district is in the Cargo Muchacho Mountains, Imperial County, California, northwest of the reservation.

The earliest known mining in the district occurred in a brief period from 1780 to 1781 when placer fields were worked. Completion of the Southern Pacific Railroad sparked renewed discovery in 1877; by 1900 the bulk of the $5 million worth of gold produced from the district had been mined. Aside from gold, this area had small amounts of copper, kyanite, sericite, and wollastonite (Morton, 1977).

The district is predominantly underlain by pre-Mesozoic crystalline rocks; lesser quartzite-sericite schist, arkose and granitic intrusive rocks are present (Morton, 1977). Ore deposits are generally confined to the southwestern slopes of the mountains and show a common N. 35 W. trend (Morton, 1977).

### Southeastern Chocolate Mountains District

This area is 16 miles northeast of Yuma, Arizona. Low-lying dissected terraces with intermittent highlands comprise most of the area, with elevations ranging from 200 to 2,000 feet above sea level (Morton, 1977).

The earliest California mineral production was from this area; in 1779 local Indians worked the Potholes placers. From 1850 to the present, the district has produced $2 million to $3 million worth of gold. Most mining was by dry placer methods because of the lack of water on the terraces (Root, 1923). Area lode gold deposits are pre-Tertiary in age and occur in metaconglomerate and metagranite (Morton, 1977, Crawford, 1896, and Tucker, 1942). There appears to be a relationship between gold occurrences and the Mesozoic granitic intrusive; however, small amounts of gold are also known to occur in schist and gneiss. A potential exists for future discovery of subsurface lode veins and placers in deeper areas in the terraces.

### Cocopah

Little mineral potential is evident on the Cocopah Indian Reservation. If present, metallic mineral deposits would probably be placer gold in Colorado River bars to the west. No deposits are known, and no production is recorded for this section of the river.

### Nonmetallic Mineral Resources

Geologic and topographic maps indicate abundant alluvial material on both reservations with concentrations of gravel in northern sections of the Fort Yuma. The Fort Yuma has numerous operating sand and gravel pits, the Cocopah has none.

Gravel for building and concrete appears to be the most marketable product, although the alluvium could also be a potential source for secondary road fill.

Table 1 describes the mines and prospects in or near the reservations.

## ENERGY RESOURCES

### Uranium

No uranium occurrences have been recorded within either of the reservations; however, radioactively anomalous areas to the east and in the Cargo Muchacho Mountains of the Fort Yuma Reservation indicate some potential for local uranium deposition (Fred Files, personal commun., 1980).

On the Fort Yuma reservation, alluvium containing organic debris has the potential for uranium deposition. In a reducing environment, uranium in ground water would precipitate and possibly concentrate in small roll-front deposits.

## Geothermal

No geothermal potential is indicated in the Fort Yuma Indian Reservation even though it lies between two confirmed geothermal areas. Fifty miles west, several wells have been drilled in the high potential area around the Salton Sea. The Salton Sea area lies along the San Andreas Fault system (Morton, 1977). Radium Hot Springs is approximately 40 miles east. This thermal spring group has temperatures of 140ºF (Wilson, 1933).

There is one geothermal well in sec. 11, T. 20 S., R. 23 W., G & S.R.B.M., four miles east of the East Cocopah Indian Reservation near the Algadones Fault. No known extensions of the fault occur on the reservation (Dutcher, 1972).

## Petroleum

The reservations have no known petroleum resources.

## MINERAL LEASING

Permits to prospect definite areas of Indian lands are available to the public (25 CFR 171.27a). The duration of the lease for prospecting must be stated in the application, and no ores may be removed other than for testing or assaying purposes. Unless negotiated in advance, prospecting permits do not include the right to leases or any discoveries made on Indian lands. Further information concerning leases and permits can be obtained from the California and Arizona offices of BIA.

## RECOMMENDATIONS FOR FURTHER WORK

The geology of the Yuma and Cocopah Reservations is incompletely known and should be evaluated further for potential mineral resources. Because of the extensive alluvial cover, the geologic evaluation should include detailed geochemical, gravity, and aeromagnetic surveys. The gravity and aeromagnetic surveys can aid in (1) inferring the geology underlying the sedimentary cover, (2) determining thickness of sedimentary cover, (3) locating intrusive bodies, (4) defining target areas where alteration has reduced the magnetization of the rocks, and (5) identifying anomalous concentrations of magnetic rocks. Geologic mapping of the reservation lands should be directed toward distribution of altered and mineralized rocks to isolate areas of potential for mineral deposits, industrial minerals, salines and lightweight aggregates.

More specifically, the following work is recommended for the Fort Yuma reservation:

1. Examine known lode deposits to determine possible extensions into the reservation.

2. Sample well and spring water for subsurface uranium or metallic minerals.

3. Undertake appropriate geophysical studies to locate subsurface extensions of mineralized structures found outside the reservation.

# REFERENCES

Barnett, Frank (U.S.A.E.T.L., Liaison Officer, Yuma Proving Grounds, Yuma, Ariz., 85364), unpublished maps.

Beck, W. A., and Haase, Y. D., 1974, Historical atlas of California: University of Oklahoma Press, Norman, Okla., 210 p.

Beinler, S., Kovack, R. L., and Allen, C. R., 1964, Geophysical framework of the northern end of Gulf of California structural province, in Marine geology of the Gulf of California--A symposium: American Association of Petroleum Geologists Memoir 3, p. 126-143.

Bowen, E. O., Gray, C. H., Jr., and Evans, J. R., 1973, Limestone and dolomite resources of California: The mineral economics of the carbonate rocks: California Division of Mines and Geology Bulletin 194, 60 p.

Bradley, W. W., 1942, Quarterly chapter of state mineralogist's report 35: California Division of Mines and Geology, Division of Mines, v. 38, no. 2, 220 p.

Brown, R. H.,-Harshbarger, J. W., and Thomas, H. E., 1956, Analysis of basic data concerning ground water in Yuma area, Arizona: U.S. Geological Survey Open File Report 56-016.

Campbell, Ian, and Wright, L. A., 1950, Kyanite paragenesis of Ogilby, California [abs.]: Geological Society of America Bulletin, v. 61, no. 12, pt. 2, p. 1520-1521.

Clark, S. H., Jr., and Nilsen, T. H., 1973, Displacement of Eocene strata and implications for the history of offset along the San Andreas fault, central and northern California: Stanford University Publications in Geological Science, v. 13, p. 358-367.

Clark, W. B., 1970, Gold districts of California: California Division of Mines and Geology Bulletin 193, p. 153-156, and p. 163.

Cooley, M. E., and Davidson, E. S., 1963, Synoptic Cenozoic geologic history of the Colorado Plateaus and Basin and Range provinces of Arizona [abs.]: Geological Society of America, Rocky Mountain Section, 16th Annual Meeting, p. 27.

Crawford, J., 1894, Mines and mining products of California: California State Mining Bureau - Twelfth Report of the State Mineralogist, p. 237-243.

Cross, J. L., and others, eds., Arizona: Its people and resources: The University of Arizona Press, 368 p.

Crowe, B. M., 1973, Cenozoic volcanic geology of the southeastern Chocolate Mountains, California: Santa Barbara, University of California, Ph. D. thesis, 117 p.

____,1978, Cenozoic volcanic geology and probable age of inception of basin-range faulting in southeastern-most Chocolate Mountains, California: Geological Society of America Bulletin, v. 89, p. 251-264.

Crowe, B. M., Crowell, J. C., and Krummenaeker, Daniel, 1979, Regional stratigraphy, K-Ar ages, and tectonic implications of Cenozoic volcanic rocks, southeastern California: American Journal of Science, v. 279, p. 186-216.

Crowell, J. C., 1974, The Orocopia Thrust, south-eastern California [abs.]: Geological Society of America, Abstracts with Programs, v. 6, no. 3, p. 159.

____,1975, Geologic sketch of the Orocopia Mountains, southeastern California: California Division of Mines and Geology Special Report 118, p. 99-110.

____,1975, ed., San Andreas fault in southern California: A guide to San Andreas fault from Mexico to Carrizo Plain: California Division of Mines and Geology Special Report 118, Sacramento, Calif., 272 p.

Crowell, J. C., and Sylvester, A. G., eds., 1979, Tectonics of the juncture between the San Andreas fault system and the Salton Trough, southern California, a guidebook: Department of Geological Sciences, University of California, Santa Barbara, for Annual Meeting of Geological Society of America.

Damon, P. E., 1965, Correlation and chronology of ore deposits and volcanic rocks: University of Arizona, Geochronology Laboratory Annual Progress Report C00-689-50, 60 p.

Dibblee, T. W., 1954, Geology of the Imperial Valley region, California, in Jahns, R. H., ed., Geology of southern California: California Division of Mines Bulletin 170, ch. 2, cont. 2, p. 21-28, scale 1:375,000.

Dillon, J. T., 1975, Geology of the Chocolate and Cargo Muchacho Mountains, southeastern-most California [abs.]: Geological Society of America, Abstracts with Programs, v. 7, no. 3, p. 311.

____,1975, Remnants of a late Oligocene-early Miocene plutonic-volcanic belt in southeastern California and southwest Arizona [abs.]: Geological Society of America Abstracts with Programs, v. 7, no. 5, p. 605.

Dillon, J. T., and Haxel, G. B., 1975, The Chocolate Mountain-Orocopia Vincent thrust system as a tectonic element of late Mesozoic California [abs.]: Geological Society of America Abstracts with Programs, v. 7, no. 3, p. 311.

Downs, Theodore, and Woodward, G. D., 1961, Middle Pleistocene extension of the Gulf of California into the Imperial Valley, in Abstracts for 1961: Geological Society of America Special Paper 68, p. 21.

Dutcher, L. C., Hardt, W. F., and Moyle, W. R., 1972, Preliminary appraisal of ground water in storage with reference to geothermal resources in the Imperial Valley area, California: U.S. Geological Survey Circular 649, 57 p.

Eberly, L. D., and Stanley, T. B., Jr., 1978, Cenozoic stratigraphy and geologic history of south-western Arizona: Geological Society of America Bulletin, v. 89, p. 921-940.

Elders, W. A., Rex, R. W., Meidav, T., Robinson, P. T., and Beihler, S., 1972, Crustal spreading in southern California: Science, v. 178, no. 4056, p. 15-24.

Frank, F. J., 1963, Progress report on subsurface geologic investigation in the Yuma area: U.S. Geological Survey Open-File Report, 7 p.

Goldman, H. B., 1968, Sand and gravel in California, an inventory of deposits, southern California: California Division of Mines and Geology Bulletin 180-C, 55 p.

Hadley, J. B., 1942, Manganese deposits in the Paymaster mining district: U.S. Geological Survey Bulletin 931-S, p. 459-473.

Hamilton, W. B., 1969, Mesozoic California and the underflow of the Pacific mantle: Geological Society of America Bulletin, v. 80, p. 2409-2430.

Hawkins, J. W., 1970, Petrology and possible tectonic significance of late Cenozoic volcanic rocks, southern California and Baja California: Geological Society of America Bulletin, v. 87, p. 3323-3338.

Haxel, G. B., 1973, Pre-Tertiary geology of the Pichacho area, southeastern California [abs.]: Geological Society of America, Abstracts with Programs, v. 5, no. 7, p. 51-52.

____,1975, The Orocopia Schist and the Chocolate Mountain thrust in the Picacho-Peter Kane Mountain area, southeastern-most California: Santa Barbara, University of California, Ph.D. thesis, 277 p.

Henshaw, P. C., 1942, Geology and mineral deposits of the Cargo Muchacho Mountains, Imperial County, California: California Journal of Mines and Geology, v. 38, no. 2, p. 147-196.

Jahns, R. H., 1954, Geology of the Peninsular Range province, southern California and Baja California, in Jahns, R. H., ed., Geology of southern California: California Division of Mines Bulletin 170, chap. 11, cont. 3, scale 1:375,000.

Jones, E. L., Jr., 1919, Deposits of manganese in southeastern California: U.S. Geological Survey Bulletin 710E, p. 185-189, 200-201.

Karig, D. E., and Jensky, W., 1972, The proto-Gulf of California: Earth and Planetary Science Letters, v. 17, p. 169-174.

Keith, S. B., 1978, Index of mining properties in Yuma County, Arizona: Arizona Bureau of Geology and Mineral Technology Bulletin 192, 185 p.

Kelso, M. M., Martin, W. E., and Mack, L. E., 1973, Water supplies and economic growth in an arid environment: An Arizona case study: University of Arizona Press, Tucson, 327 p.

King, R. E., 1939, Geologic reconnaissance in northern Sierra Madre Occidental of Mexico: Geological Society of America Bulletin, v. 50, p. 1625.

Korach, R. L., Allen, R. A., and Press, Frank, 1962, Geophysical investigation in the Colorado delta region: Journal of Geophysical Research, v. 67, no. 7, p. 2845-2877.

Larson, R. L., Menard, H. W., and Smith, S. H., 1968, Gulf of California: A result of ocean-floor spreading in southern California: Institute of Geophysics and Planetary Physics, Riverside, University of California.

Longwell, C. R., 1954, History of the lower Colorado River and the Imperial depression, in Jahns, R. H., ed., Geology of southern California: California Division of Mines Bulletin 170, chap. 5, p. 53-56.

Love, Frank, 1974, Mining camps and ghost towns: A history of mining in Arizona and California along the lower Colorado: Los Angeles, Westernlore Press, 192 p.

Luchitta, I., 1972, Early history of the Colorado River in the Basin and Range Province: Geological Society of America Bulletin, v. 83, p. 1933-1948.

Lydon, P. A., 1957, Sulfur and sulfuric acid, in Wright, L. A., ed., Mineral commodities of California: California Division of Mines Bulletin 176, p. 614.

Mattick, R. E., Olmsted, F. H., and Zohdy, A. A. R., 1973, Geophysical studies in the Yuma area, Arizona and California: U.S. Geological Survey Professional Paper 726-D, 36 p.

Merriam, R., and Bandy, O. L., 1965, Source of upper Cenozoic sediments in Colorado delta region: Journal of Sedimentary Petrology, v. 35, no. 4, p. 911-916.

Metzger, D. G., 1968, The Bouse Formation (Pliocene) of the Parker Blythe-Cibola area, Arizona and California, in Geological Survey research 1968, Chapter D: U.S. Geological Survey Professional Paper 600-D, p. 126-136.

Morton, P. K., 1962, Reconnaissance geologic map of parts of the Picacho Peak, Laguna, Ogilby, Grays Well Northeast, and Yuma quadrangles, California: California Division of Mines and Geology reconnaissance mapping for State Geologic Map (El Centro sheet), 1960-1962.

____,1977, Geology and mineral resources of Imperial County, California: California Division of Mines and Geology - County Report, no. 7, 104 p.

Muffler, L. J. P., and Doe, B. R., 1968, Composition and mean age of detritus of the Colorado River delta in the Salton Sea Trough, southeastern California: Journal of Sedimentary Petrology, v. 38, p. 384-399.

National Oceanic and Atmospheric Administration, 1978, Climatological data, annual summary - California: U. S. Department of Commerce, Environmental Data and Information Service, v. 83, no. 13, 27 p.

Norris, R. M., and Norris, K. S., 1961, Algodones dunes of southeastern California: Geological Society of America Bulletin, v. 72, no. 4, p. 605-619.

Olmsted, F. H., 1968, Tertiary rocks near Yuma, Arizona [abs.]: Geological Society of America Special Paper 101, p. 153-154.

____,1972, Geology of the Laguna Dam 7½ minute quadrangle, Arizona and California: U.S. Geological Survey Geologic Quadrangle Map GQ-7074, scale 1:24,000.

Olmsted, F. H., Loeltz, O. J., and Irelan, Burdge, 1973, Geohydrology of the Yuma area, Arizona and California: U.S. Geological Survey Professional Paper 486-H, 227 p.

Olmsted, F. H., and Robison, J. H., 1964, Progress report on geologic investigations of the Yuma area and the East Mesa area of Imperial Valley, in Investigations of the water resources of the lower Colorado River area, progress report: U.S. Geological Survey Open-File Report 3, p. 25-51.

Peterson, D. L., and others, 1967, Principal facts for gravity stations in the Yuma area, Arizona, and Blythe, California: U.S. Geological Survey Open-File Report.

Popenoe, W. P., 1954, Mesozoic formations and faunas, southern California, in Jahns, R. E., ed., Geology of southern California: California Division of Mines Bulletin 170, chap. 3, p. 53-56.

Rex, R. W., 1970, Investigation of geothermal resources in the Imperial Valley and their potential value for desalination of water and electricity production: Institute of Geophysics and Planetary Physics, University of California, Riverside.

Rex, R. W., and Meidar, Tsui, 1970, Geophysical investigations for geothermal energy sources, Imperial Valley, California, Phase I 1968 field project: Institute of Geophysics and Planetary Physics, University of California, Riverside.

Root, L. L., 1923, Gold placers of California: California State Mining Bureau Bulletin 92, p. 155.

Sampson, R. J., 1932, Placers of Southern California: California Mining Bureau State Mineralogist Report 28, p. 68.

Sampson, R. J., and Tucker, W. B., 1942, Mineral resources of Imperial County: California Journal of Mines and Geology-State Mineralogist Report, v. 38, no. 2, p. 118, 124, and 194.

Silver, L. T., 1974, Precambrian and "Precambrian(?)" crystalline rocks of the southwestern Basin and Range province of California and Arizona [abs.]: Geological Society of America Abstracts with Programs, v. 6, no. 3, p. 253-254.

Smith, P. B., 1970, New evidence for a Pliocene marine embayment along the lower Colorado River, California and Arizona: Geological Society of America Bulletin, v. 81, p. 1417-1420.

Stanley, G. M., 1966, Deformation of Pleistocene Lake Cahuilla shoreline, Salton Sea basin, California, in Abstracts for 1965 [abs.]: Geological Society of America Special Paper 87, 366 p.

Stanton, K. B., 1978, Index of mining properties in Yuma County, Arizona: Arizona Bureau of Geology and Mining Technology Bulletin 192, p. 181.

Sykes, Geofry, 1937, The Colorado delta: American Geophysical Society Special Publications 19; Carnegie Institution of Washington Publication 460.

Tucker, W., 1926, District report of mining engineers - Los Angeles Field Division, Imperial County: California State Mining Bureau, State Mineralogist Report 22, p. 248-285.

U.S. Army Corps of Engineers, 1963, Analogs of Yuma terrain in the southwest United States desert: Waterways Experiment Station Technical Report no. 3-630, rep. 5, v. 1, 45 p.; v. 2, 65 p.

U.S. Bureau of Indian Affairs, 1978, Information profiles of Indian reservations in Arizona, Nevada, and Utah: Bureau of Indian Affairs, Phoenix Area Office, p. 27-30.

U.S. Bureau of Indian Affairs, Fort Yuma Indian Reservation (detailed soil survey): U.S. Bureau of Indian Affairs, scale 1:600.

U.S. Bureau of Mines, 1980, Individual property files and Minerals Availability System.

U.S. Bureau of Reclamation, 1942, Imperial East Mesa (land classification): scale 1:62,500.

____,1949, Pilot Knob Mesa (land classification): scale 1:62,500.

____,1952, Colorado River bottom lands (land classification): scale 1:31,250.

____, 1961, Colorado River flood plain (soil survey): scale 1":600'.

____,1971, Geothermal resource investigations, Imperial Valley, California: Status Report, Region 3.

U.S. Department of Agriculture, 1904, Soil survey of the Yuma area (Arizona and California): scale 1:62,500.

____,1929, Soil survey of the Yuma-Walton area (Arizona and California): scale 1:62,500.

Vuich, J. S., and Wilt, J. C., 1974, Bibliography of the geology and mineral resources of Arizona, 1965-1970: Arizona Bureau of Mines Bulletin 190, 155 p.

Willis, C. F., 1916, Arizona: Arizona State Bureau of Mines, University-of Arizona, Tucson, Bulletin no. 6 (Economic Series no. 3), 16 p.

Wilson, E. D., 1933, Geology and mineral resources of southern Yuma County, Arizona: Arizona Bureau of Mines Bulletin 134, 236 p.

____,1960, Geologic map of Yuma County, Arizona: Arizona Bureau of Mines, University of Arizona, scale 1:375,000.

____,1978, Gold placers and placering in Arizona: Arizona Bureau of Mines and Geology and Mining Technology Bulletin 168, 124 p.

Wilson, E. D., Cunningham, J. B., and Butler, G. M., 1967, Arizona lode gold mines and gold mining: Arizona Bureau of Mines Bulletin 137.

Wilson, E. D., and Moore, R. T., 1969, Geologic map of Arizona: U.S. Geological Survey and Arizona Bureau of Mines.

Woodring, W. P., 1931, Distribution and age of the Tertiary deposits of the Colorado Desert: Carnegie Institution of Washington Publication 148, p. 1-25.

Woodward, G. D., 1961, Stratigraphic succession of the west Colorado Desert, San Diego and Imperial Counties, southern California [abs.]: Geological Society of America Bulletin, v. 72, no. 72, pt. 2, (Program, Cordilleran Section Meeting, p. 73-74).

Wright, L. A., Chesterman, C. W., and Norman, L. A., Jr., 1954, Occurrence and use of non-metallic commodities in southern California, in Jahns, R. H., ed., Geology of southern California: California Division of Mines Bulletin 170, ch. 8, pt. 7, p. 59-74.

Yeats, R. S., 1968, Rifting and rafting in the southern California borderland: Stanford University Publications in Geological Science, v. 11, p. 307-322.

Table 1.—Description of mines and prospects in the Fort Yuma Indian Reservation and surrounding area, Arizona and California

[Numbers correlate with locations on figure 2]

| Map number | Name | Location | Commodity | Description |
|---|---|---|---|---|
| 1 | Stone Face | NW1/4 sec. 26, T. 15 S., R 21 E., S.B.B.M. | Gold, silver, copper | Extreme southeast portion of the Cargo Muchacho Mountains, 9.5 miles northwest of Yuma. Small lenticular bodies of quartz trend N. 80° E. in quartz monzonite. Average sizes are a few feet wide and a few tens of feet long (Morton, 1977). |
| 2 | Valley Sand and Gravel pit | SE1/4 sec. 2, T. 16 S., R. 22 E., S.B.B.M. | Sand and gravel | Production unknown; thought to be presently active (USBM, 1980). |
| 3 | Colorado placer | Sec. 19, T. 15 S., R. 23 E., S.B.B.M. | Gold | Small operation processed 1,300 yds$^3$ of placer material and produced 17.3 ounces gold. Last recorded production was in 1956 (USBM, 1980). |
| 4 | Jude Mine | Cen. sec. 34, T. 8 S., R. 23 W., G & S.R.B.M. | Gold, silver, iron | Shaft and open cut explore gold-bearing iron stained quartz veins. Country rock is Mesozoic or Laramide gneiss. Worked originally in the early 1900's and again in 1939-1940 and 1947. Production of 450 tons of ore that assayed 0.3 ounce per ton gold with minor silver (Stanton, 1978; Wilson, 1933). |

| Map number | Name | Location | Commodity | Description |
|---|---|---|---|---|
| 5 | Yuma County no. 1 pit | Sec. 20, T. 8 S., R. 22 W., S.B.B.M. | Sand and gravel | Production unknown, thought to be presently active (USBM, 1980) |
| 6 | Trio (Duncan) Mine | SW1/4 sec. 19, T. 15 S., R. 24 E., S.B.B.M. | Gold | Three-foot-wide vein strikes north-east and dips 50° to the northwest. Country rock is a porphyroblastic metagranite. The property was most active from 1933 to 1935; ceased production in 1936 when construction of the All American Canal flooded the workings. The property is developed by three shallow inclined shafts (Norton, 1977). |
| 7 | Valenzuela pit | Sec. 28, T. 7 S., R. 22 W., G. & S.R.B.M. | Sand and gravel | Production unknown; thought to be presently active (USBM, 1980). |
| 8 | Three C's (Duncan) Mine | N1/4 sec. 24, T. 15 S., R. 23 E., S.B.B.M. | Gold | Free gold-bearing brecciated quartz vein striking N. 50° W. and dipping 30° SW. Fault zone is approximately 10 to 20 feet wide and contains angular white quartz fragments. Wall rocks are metaconglomerate and porphyroblastic metagranites. Small amounts of galena and wolframite are reported to occur in quartz fragments. Workings consist of a 30 foot inclined shaft with levels at 80, 175, 225, and 285 feet down the incline. Horizontal workings total about 300 feet (Morton, 1977; Tucker, 1942; and Crawford, 1896). |

Table 1.--Description of mines and prospects in the Fort Yuma Indian Reservation and surrounding area, Arizona and California--Continued

| Map number | Name | Location | Commodity | Description |
|---|---|---|---|---|
| 9 | Potholes placer | N1/2 sec. 25, T. 15 S., R. 23 E., S.B.B.M. | Gold | Gold-bearing gravels were worked extensively by Indians as early as 1780. Production is estimated at $2,000,000 in gold but records are very poor. The area was worked as a dry placer with Mexican miners hauling some dirt to the Colorado River. Placer source appears to be the Three C's lode deposit, one mile to the north (Morton, 1977; Crawford, 1942; and Tucker, 1926). |
| 10 | Duncan Mine | Sec. 19, T. 15 S., R. 24 E., SBBM | Gold | Approximately 1.5 miles northeast of Laguna Dam and 16 miles northeast of Yuma, Arizona. The vein trends N. 40° W. and dips 35° SW. Thickness averages 3 to 10 feet; mineralized zone is associated with a schist granite contact. Exploration is by a 200 foot shaft. Average ore assayed 0.55 ounce gold per ton in 1898 (Sampson and Tucker, 1942; Tucker, 1926). |

Table 1.--Description of mines and prospects in the Fort Yuma Indian Reservation and surrounding area, Arizona and California--Continued

| Map number | Name | Location | Commodity | Description |
|---|---|---|---|---|
| 11 | Laguna Dam placers | N1/2 sec. 23, T. 7 S., R. 22 W., G. & S.R.B.M. | Gold | These placers were formed by erosion of steep schist and granite gneiss hills that rise 250 feet above the Colorado River. Quartz veins carry gold which has "rusty" placer gold characteristics. Dredging was attempted in 1884 or 1885 but the dredges were destroyed by flood. Potholes up to 100 feet above the river carry coarse gold. These placers are very similar to the Potholes placer, directly across the Colorado River in California (Wilson, 1978). |
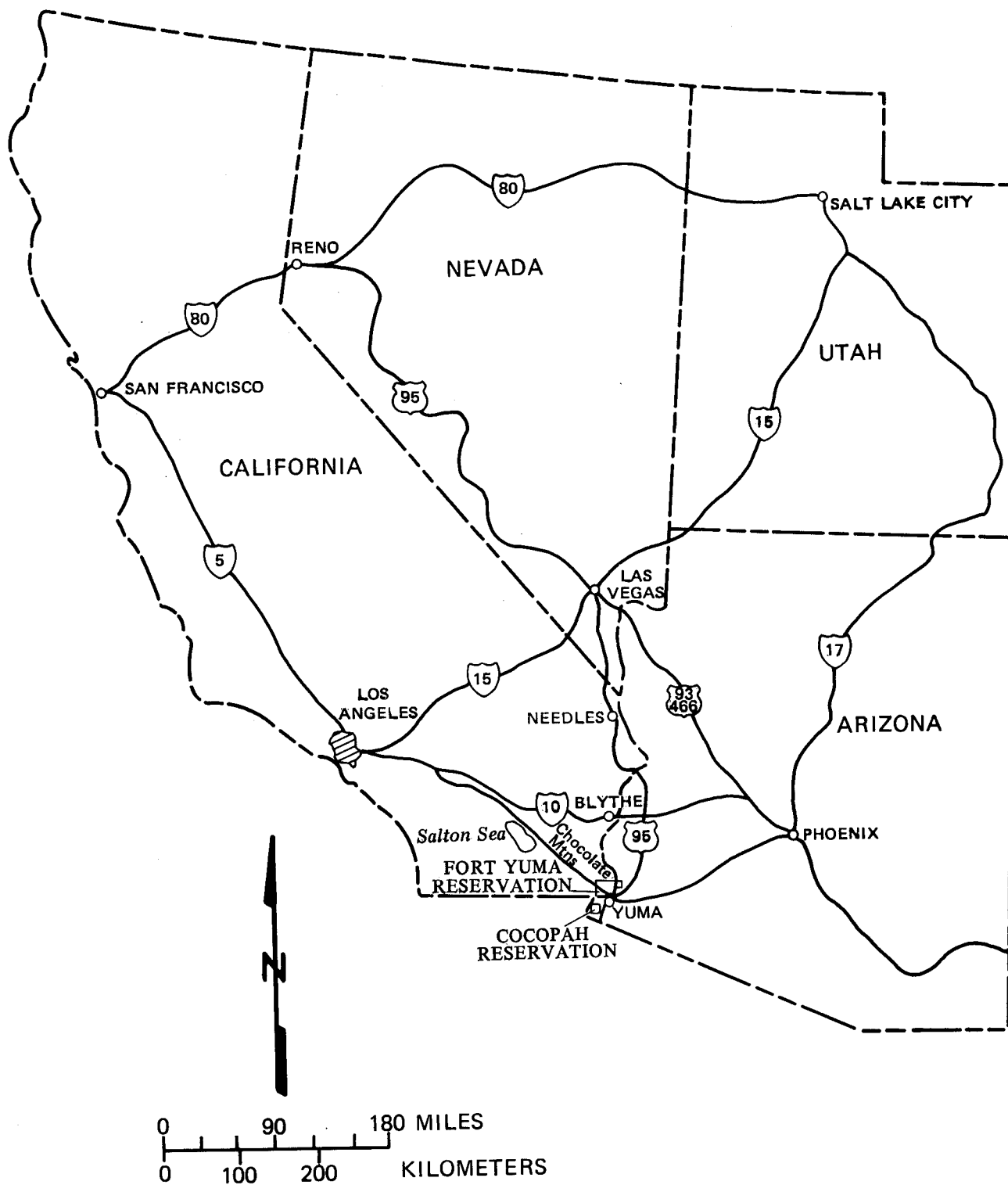
**Figure 1.** Location map for Fort Yuma and Cocopah Indian Reservations, Arizona and California.

**Figure 2.** Mineral occurrences of the Fort Yuma Indian Reservation and surrounding area, Arizona and California.
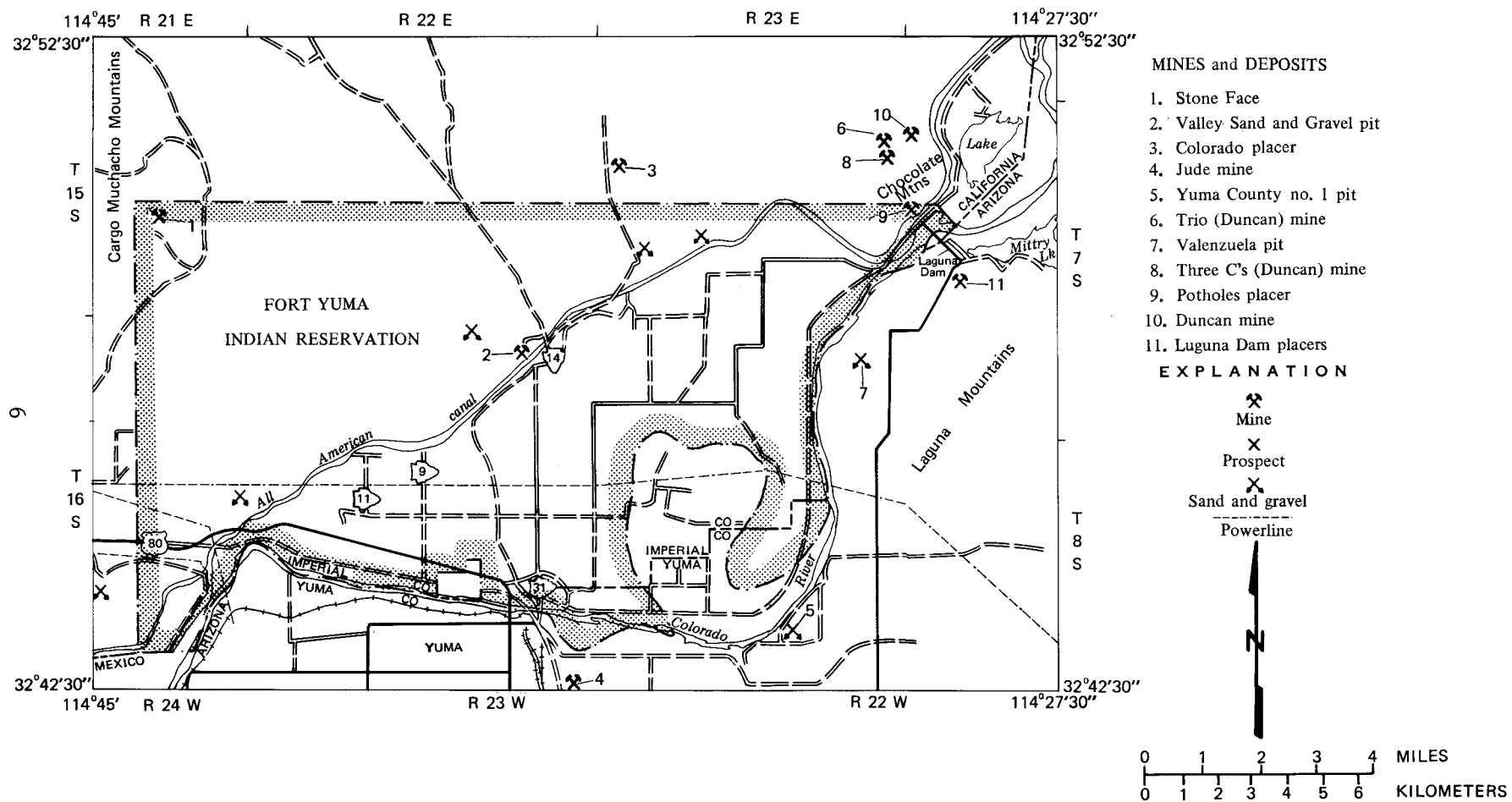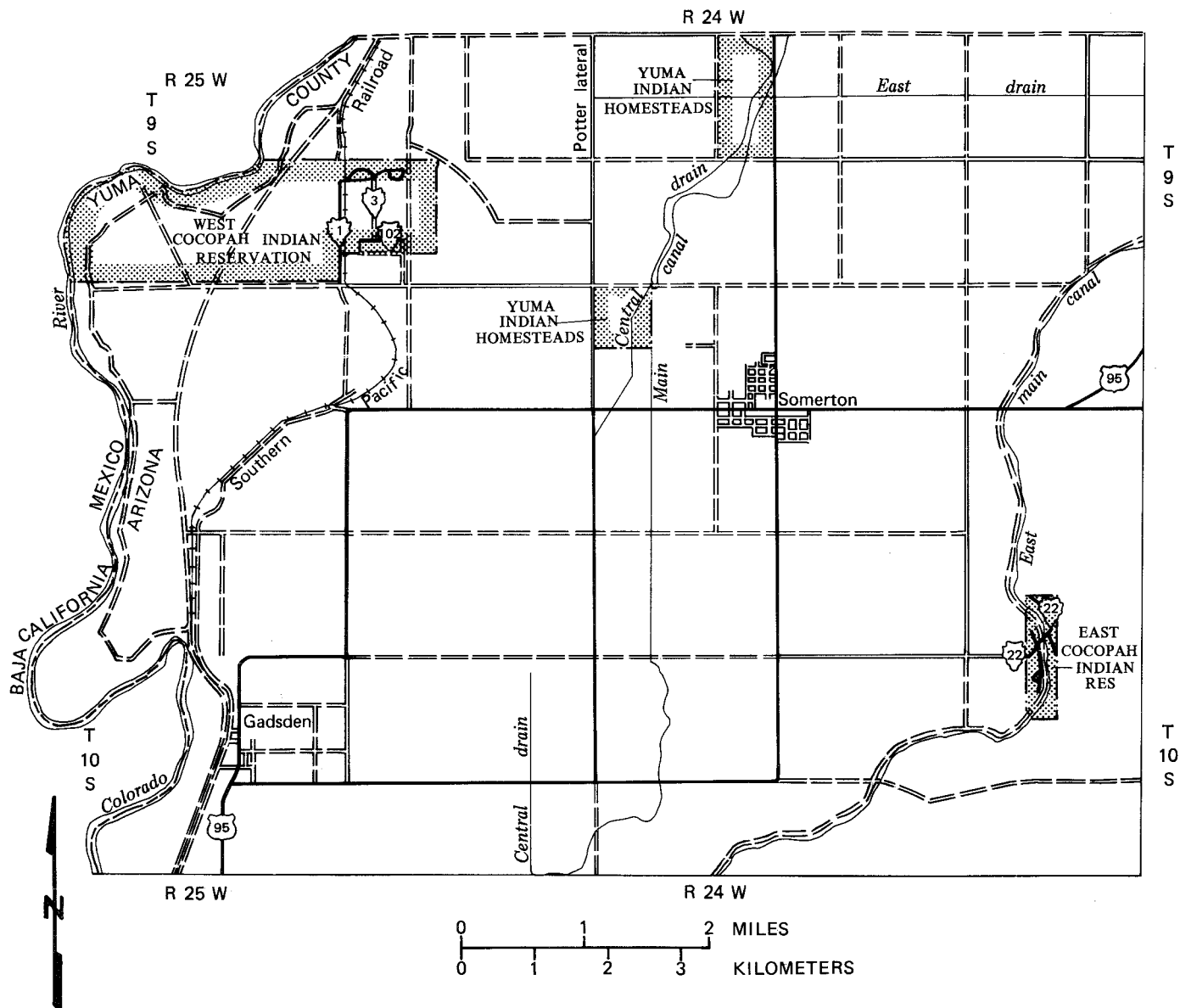
**Figure 3.** Cocopah Indian Reservation land parcels, Arizona.

**EXPLANATION**

Indian Reservation

0       3       6   MILES

0   3   6   9   KILOMETERS
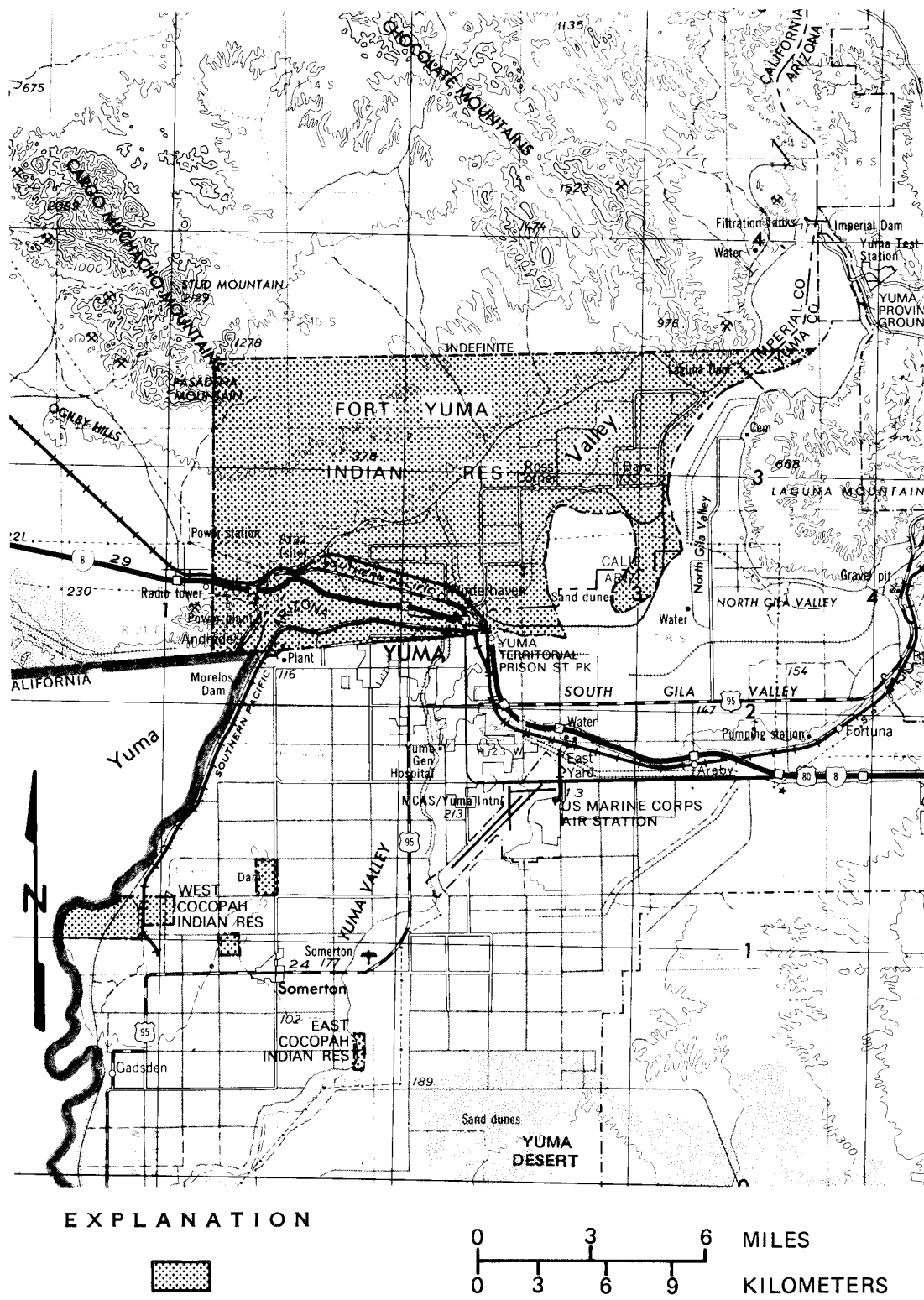
**Figure 4.** Topographic map of the Fort Yuma and Cocopah Indian Reservations and surrounding area, Arizona and California.
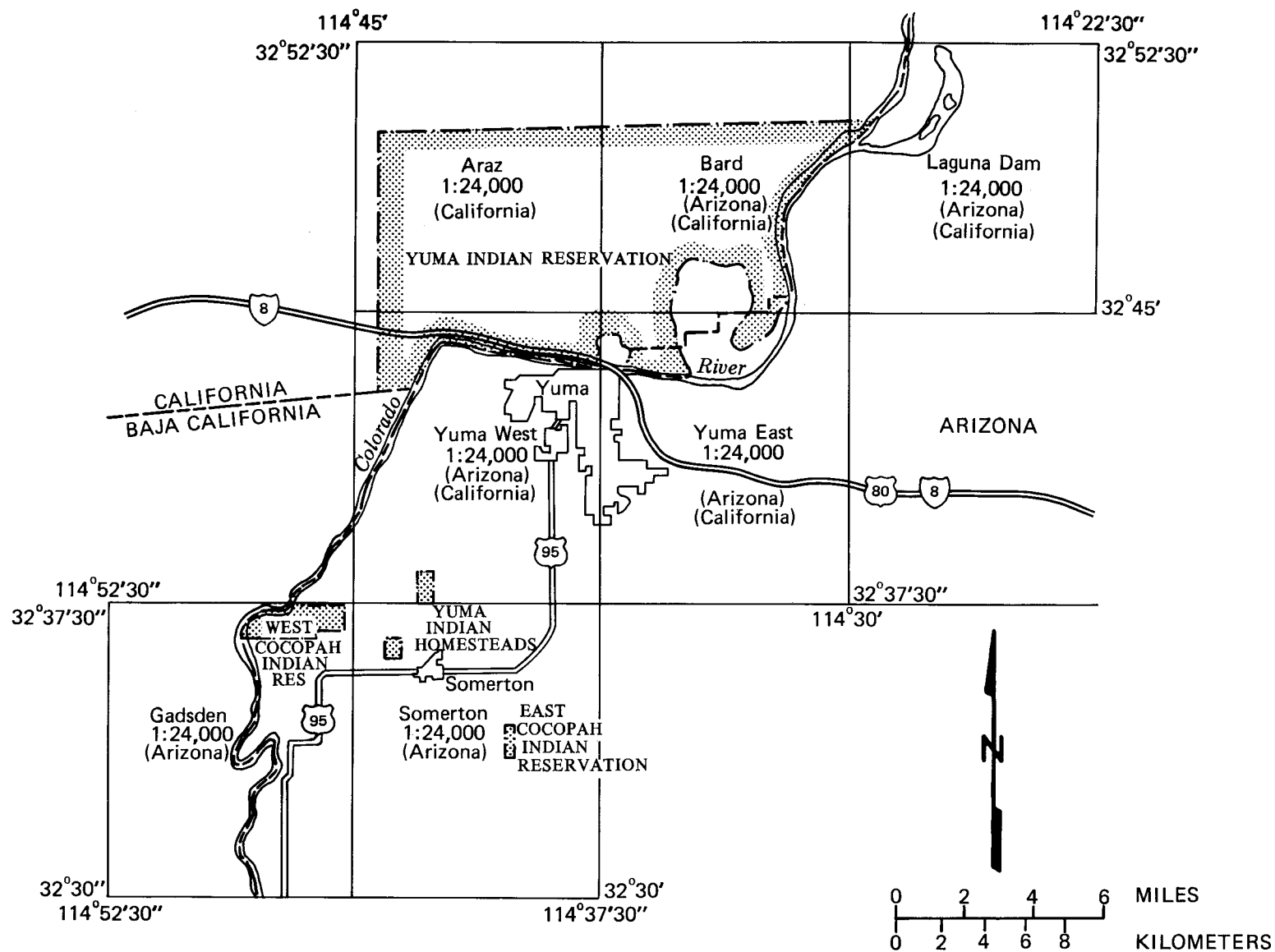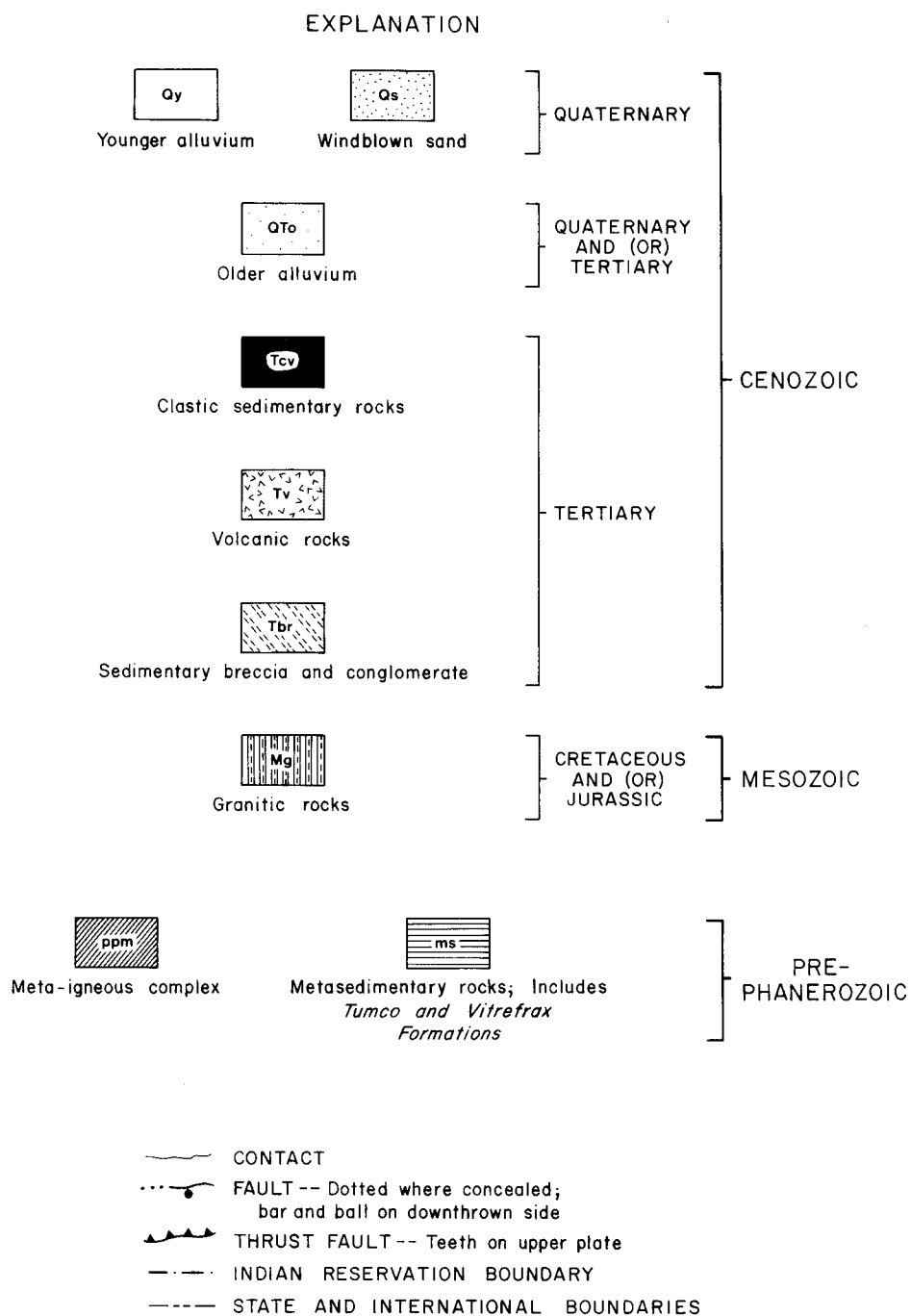
**Figure 5.** Topographic map index of the Fort Yuma and Cocopah Indian Reservations, Arizona and California.
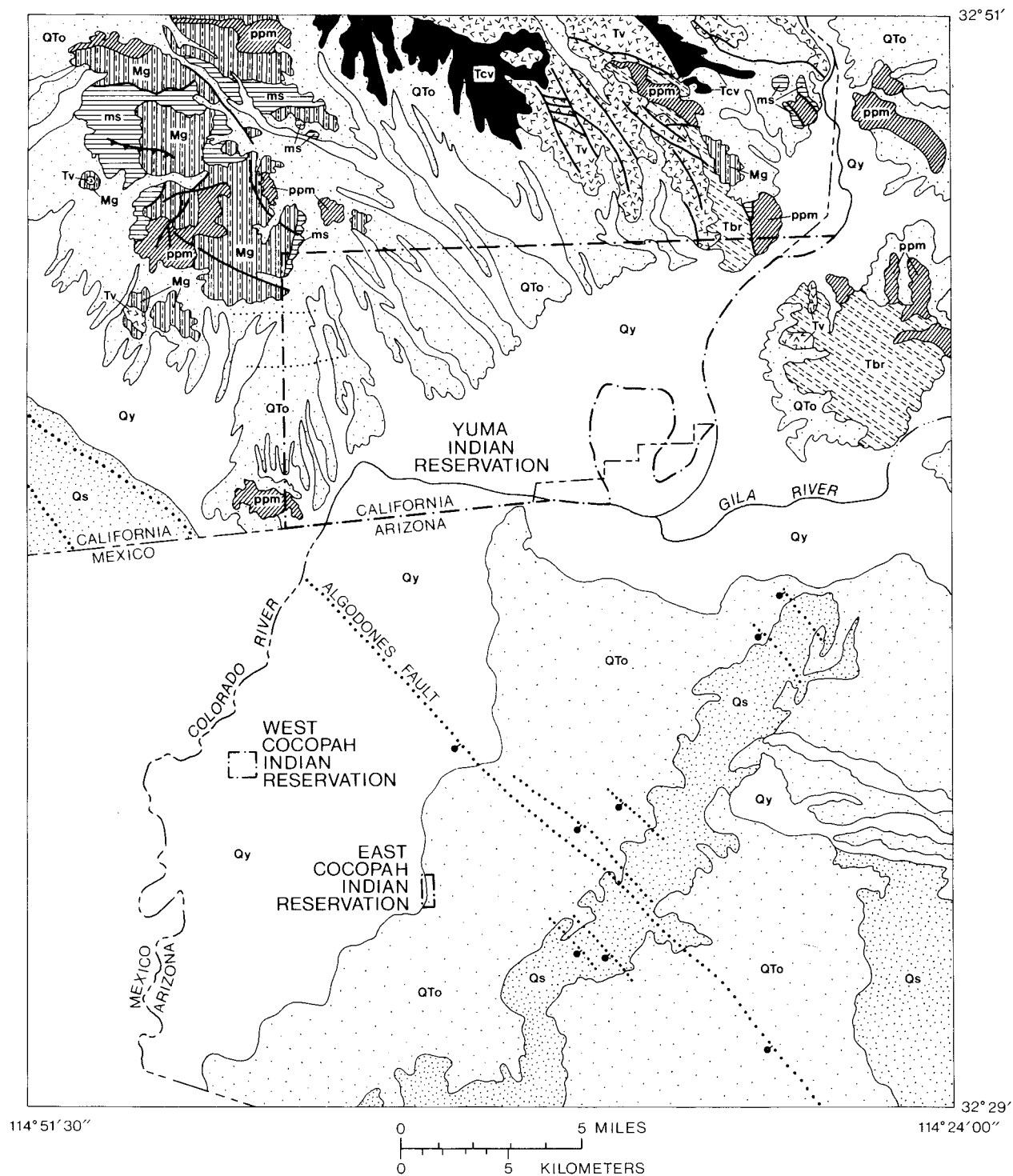
**Figure 6.** Generalized geologic map of the Fort Yuma and Cocopah Indian Reservations, Arizona and California. See Figure 6a for explanation.

EXPLANATION

| | | |
|---|---|---|
| **Qy** | **Qs** | QUATERNARY |
| Younger alluvium | Windblown sand | |

**QTo**

Older alluvium

QUATERNARY AND (OR) TERTIARY

**Tcv**

Clastic sedimentary rocks

**Tv**

Volcanic rocks

**Tbr**

Sedimentary breccia and conglomerate

TERTIARY

CENOZOIC

**Mg**

Granitic rocks

CRETACEOUS AND (OR) JURASSIC

MESOZOIC

**ppm**

Meta-igneous complex

**ms**

Metasedimentary rocks; Includes *Tumco and Vitrefrax Formations*

PRE-PHANEROZOIC

———— CONTACT

···—⌣— FAULT -- Dotted where concealed; bar and ball on downthrown side

⊥⊥⊥⊥ THRUST FAULT -- Teeth on upper plate

—·—· INDIAN RESERVATION BOUNDARY

—--— STATE AND INTERNATIONAL BOUNDARIES

**Figure 6a.** Explanation for Figure 6.

**Figure 7.** Stratigraphic column in the vicinity of the Fort Yuma and Cocopah Indian Reservations. From Olmsted and others (1973).